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Efficiency of small-scale firewood processing operations in Southern Europe

This is the author's manuscript

Original Citation:

Availability:

This version is available <http://hdl.handle.net/2318/1616685> since 2016-11-25T14:50:44Z

Published version:

DOI:10.1016/j.fuproc.2014.01.025

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(Article begins on next page)

1 Efficiency and cost of firewood processing technology and 2 techniques

3

4 Abstract

5 The study determined the performance of small-scale commercial
6 firewood processing operations under the typical work conditions of
7 southern Europe. In particular, five units were tested, fed with the same
8 2.1-m long beech logs. All machines were tested with sorted and unsorted
9 logs. Productivity varied between 1.1 and 2.1 t h⁻¹, and cost between 20
10 and 39 € t⁻¹. There were significant differences between machines, which
11 may partly be attributed to operator effect. Feeding the machines with
12 sorted logs has a strong and significant effect on the productivity of all
13 machines on test, increasing production by 40% and reducing cost by
14 34%. Fuel use varied between 1.3 and 2.8 l t⁻¹. The energy balance was
15 always very favourable. The ration between output and input was never
16 smaller than 59 and peaked at 130. In other words, processing required
17 about 1% of the energy contained in the firewood - or 1.7% in the worst
18 case. The productivity figures reported in this experiment were much lower
19 than reported for northern Europe, which seems to confirm the significant
20 effect of regional work conditions – especially different wood species - on
21 firewood processing performance.

22

23 **Keywords:** biomass, energy, productivity, forestry, beech

24

25 Introduction

26 The global consumption of firewood is estimated at over 1.5 billion m³ per
27 year (Parikka 2004). Use is especially intense in the developing countries,
28 where it accounts for 80% of the total supply of primary energy (Kear and
29 McCormick 2008). India uses about 300 million m³ of firewood per year,
30 and China over 180 million m³ (Eurostat 2013). However, traditional
31 chopped firewood is still widely used in all industrialised countries,
32 especially in rural areas (Lillemo and Halvorsen 2013). Here, firewood was
33 never been completely supplanted by fossil fuels and it enjoyed a revival
34 in recent years with the increasingly severe oil crisis (Warsco 1994). In
35 fact, Europe still uses more traditional firewood than any other industrial
36 energy wood product (Nybak et al. 2003). Although refined solid biofuels
37 (e.g. pellets and briquettes) are increasingly popular in Europe, their
38 consumption is still minor compared to traditional firewood (Trømborg et
39 al. 2008). In modern countries like Finland, Norway and Sweden firewood
40 still satisfies between 20 and 25% of the heating needs of detached
41 households (Halder et al. 2010, Lindroos 2011, Statistic Norway 2013) and
42 hovers around 5 million m³ per year and country. Firewood consumption is
43 even higher further south. It reaches 22 million m³ in France (Elyakime
44 and Cabanettes 2013) and 18 million tonnes in Italy (Caserini et al. 2008).
45 Overall, modern Europe still uses over 100 million solid m³ of firewood per
46 year, about twice as much as Canada and the US together (FAO 2007).
47 What is more, available statistics may be underestimating the size of the
48 traditional firewood market, where transaction often go unrecorded.

49

50 Compared to other fuel types, traditional chopped firewood benefits from
51 decentralised availability and a very simple production process. Once logs
52 are extracted from the forest, fuel preparation only requires cross-cutting
53 and splitting (Lindroos 2008). That allows manufacturing at a local level by
54 individuals and small-businesses, even on a part-time basis. As a result,
55 the production of firewood is often a small-scale activity run by farmers,

56 forest owners and small rural entrepreneurs (Kärhä and Jouhiahio 2009).
57 In Finland, the average firewood producer runs a part-time operation
58 processing between 50 and 150 m³ of firewood per year (Seppänen and
59 Kärhä 2003). Larger industrial operations are found in Italy, but even there
60 the average company is quite small (Spinelli et al. 2013). For this reason,
61 firewood production is important to rural development and forest
62 management, especially where coppice forests are prevalent (Lasserre et
63 al. 2011).

64

65 However economically and socially efficient, the dominance of diffused
66 small-scale rural companies implies a very limited capacity to attract
67 interest from all major actors in the technology development sector.
68 Firewood producers are so small to be virtually invisible, and they can
69 neither fund research nor leverage substantial political support for R&D in
70 the area. So far, there has been little research on traditional firewood.
71 None of the major bioenergy conferences held in Europe during the last
72 decade have addressed the future of traditional firewood (Nybakk et al.
73 2013).

74

75 In particular, firewood processing has received the least attention, possibly
76 because it is considered a very simple operation, with little potential for
77 dramatic improvement. The large productivity variation between existing
78 systems is a good witness to the contrary (Lindroos 2008), while the high
79 frequency of work accidents highlights the urgent need for further
80 development (Lindroos et al. 2008, Owen and Hunter 1993). Firewood
81 processing cost could be further reduced through improved technology
82 and work techniques, thus making firewood production safer and more
83 competitive than it currently is (Nybakk et al. 2013). At present, all the few
84 recent studies on firewood processing performance come from Nordic
85 Europe (Lindroos 2008, Kärhä and Jouhiahio 2009). Looking further back,
86 one finds more Nordic studies (Björheden 1989, Ryyänänen and Turkkila

1982, Swartström 1986). These are very good studies, but they cannot represent Europe as a whole. The work conditions encountered in Nordic countries are much different from those of Central and Southern Europe, where firewood production is much larger (Eurostat 2013). The main difference is with species, which are generally denser and harder following a southern gradient. In northern Europe, firewood is obtained from birch, pine and spruce, while beech, oak and hornbeam are dominant further south. These species have dramatically different characteristics (Table 1). Additional differences concern log length, which ranges from 2 to 6 m in northern Europe, and from 1 to 2 m in southern Europe, due to the different extraction methods (Magagnotti et al. 2012, Zimbalatti and Proto 2009).

Therefore, the goal of this study was to determine the performance of commercial firewood processing operations under the typical work conditions of southern Europe. In particular, we endeavoured to determine the productivity, cost and energy use of firewood processing with a range of different machines, under two different work techniques.

Materials and methods

Firewood processing trials were conducted in Piemonte, north-western Italy. The authors identified 5 commercial operations, run by rural entrepreneurs and considered representative of the small-scale commercial operations of southern Europe. The sample represented a wide range of small-scale firewood processing equipment, specifically designed for crosscutting and splitting firewood logs into stove wood. The main differences between the models on test were in the crosscutting device and the splitting force, the latter always exerted through a hydraulic wedge device. All the main crosscutting devices were represented, including disc saw, chainsaw and band saw (Table 2). Crosscut pieces were automatically moved to the splitter, except for the band saw unit,

118 where the cut piece was manually positioned onto the splitter plate. This
119 specific machine adopted an older traditional design, and was served by
120 two operators instead of one. All other machines were served by one
121 operator only, since the cross-cutting/splitting sequence was automatic. All
122 firewood processors were powered by old farm tractors, through the
123 tractor's power take-off. Semi-stationary use at a log yard does not require
124 a new tractor. Anything goes, as long as the engine and the power take-off
125 are still in good shape. Resorting to an old tractor allows a dramatic
126 reduction of investment cost, which is especially important for small-scale
127 rural companies.

128
129 At the time of the study, all machines were fed with 2.1 m long beech logs,
130 which they processed into 35 cm long split stove wood. Processed wood
131 was semi-fresh, with a moisture content between 35 and 40%. All
132 machines were operated by experienced professionals, who had run them
133 for several years and knew them well. These operators were reputed as
134 reliable and motivated, as they were the companies' owners or co-owners.

135
136 Machines were observed while working at the company's log yard. The
137 study compared two different work techniques, with and without
138 preliminary sorting. In the sorted treatment, the machines were fed with
139 selected logs with a small-end diameter between 18 and 25 cm. In the
140 unsorted treatment, the same machines were fed with a mix of small and
141 large logs, with a small-end diameter between 8 and 30 cm. All machines
142 were equipped with rubber-belt conveyors and discharged their product
143 into bin trailers. Each repetition consisted of a full 8-hour work day. Each
144 combination of machine and technique was replicated three times, for a
145 total of 30 replications, or 30 work days.

146
147 The experiment consisted of a typical time and motion study (Magagnotti
148 and Spinelli 2012). Work time was determined with stop watches,

149 including all delays up to a maximum duration of 30 minutes (Spinelli and
150 Visser 2009). Meal time was excluded from the records. Firewood output
151 was determined by taking all bin trailers to the certified weighbridge
152 available at the log yard.

153

154 Machine costs were estimated with the method developed within COST
155 Action FP0902 (Eliasson 2013). Machine owners provided their own
156 estimates for fuel consumption, insurance cost and maintenance cost.
157 Machine owners also declared an annual production between 300 and
158 1200 tons, which was used to estimate a mean annual usage of 500
159 hours. Labour cost was assumed to be 15 € per hour, inclusive of indirect
160 salary costs. The calculated operational cost of all teams was increased
161 by 20% to account for overhead costs (Hartsough 2003). Further detail on
162 cost calculations is shown in Table 3.

163

164 Both direct and indirect fossil energy use were estimated, reflecting the
165 same principles followed by Pellizzi (1992) in his energy analysis of Italian
166 agriculture. Direct energy use was estimated by multiplying the measured
167 diesel consumption by the energy content of 37 MJ l⁻¹ (Bailey et al. 2003),
168 and then inflating this value by 1.2 in order to account for the additional
169 fossil energy used in the production, transportation and distribution of
170 diesel fuel (Pellizzi 1992). The indirect use represented by machine
171 manufacture, repair and maintenance was estimated as 44 % of direct
172 energy use (Mikkola and Ahokas 2010). No allowance was made for the
173 embedded energy of a barn for housing the machines, on the assumption
174 that machines used in forestry often rest outdoors, or under very simple
175 makeshift structures, with a negligible energy content. Results are shown
176 in Table 3. The energy content of beech firewood with a 38% moisture
177 content was estimated at 10520 MJ t⁻¹, using the methods reported by
178 Magagnotti and Spinelli (2012).

179

180 Data were analyzed with the Statview advanced statistics software (SAS
181 1999). Since data distribution violated the normality assumption, the
182 statistical significance of the eventual differences between machine
183 models was tested with Scheffe's test, which is particularly robust against
184 such violation. The significance of differences between work techniques
185 (sorted vs. unsorted) was tested with the Wilcoxon Signed Rank Test,
186 which is the non-parametric equivalent of the standard paired t-test.

187

188 **Results**

189 All machines were simple and relatively inexpensive, as appropriate for
190 adoption by small-scale entrepreneurs (Table 3). Using second-hand farm
191 tractors gave a further contribution to containing capital outlay, which was
192 slightly higher than 30,000 € at most. That was particularly important in
193 view of the low annual usage, estimated at 500 h per year. Machine rates
194 varied between 36 and 45 € h⁻¹, including a 20% overhead surcharge.
195 Labour cost was a major contributor to machine rate, accounting for about
196 50% of the total (Figure 1). In contrast, fuel and lubricant represented less
197 than 15% of total cost, even if none of the operators used tax-free red
198 diesel, reserved to farmers.

199

200 Productivity varied between 1.1 and 2.1 t h⁻¹ (Table 4). Both Pezzolato
201 machines were significantly more productive than the others, regardless of
202 work technique. As an average, productivity increased by 40% when
203 working with sorted logs, rather than unsorted logs. In fact, different
204 machines had different sensitivity to work technique. The Pezzolato 750TL
205 had the lowest sensitivity, because it was specifically designed for
206 processing multiple logs. That reduced the effect of small log handling and
207 minimized sensitivity to sorting, which still allowed a 24% productivity
208 increase. In any case, the effect of log sorting was highly significant
209 (Wilcoxon Signed Rank test, p = 0.0007).

210

211 Processing cost ranged from 20 to 39 € t⁻¹. The BGU, Posch and
212 Pezzolato A800 operations incurred significantly higher cost than the other
213 operations, regardless of work technique. Lower productivity and relatively
214 high capital cost can explain the result for BGU and Posch. As to
215 Pezzolato A800, the higher cost was explained by its larger crew: the
216 increased labour cost was not fully offset by the higher productivity,
217 resulting in a relatively high processing cost per product unit. Work
218 technique had a highly significant effect on processing cost (Wilcoxon
219 Signed Rank test, $p = 0.0007$). Sorting logs before processing allowed
220 saving between 5 and 13 € t⁻¹, or between 20 and 34% of the original cost
221 incurred when processing unsorted logs.

222

223 Fuel use varied between 1.3 and 2.8 l t⁻¹. The machines on test were
224 divided in two groups: BGU and Posch belonged to the first group, with a
225 mean fuel use of 1.9 l t⁻¹ (sorted) and 2.6 l t⁻¹ (unsorted); Gandini and the
226 two Pezzolatos belonged to the second group, with a mean fuel use of 1.3
227 l t⁻¹ (sorted) and 1.8 l t⁻¹ (unsorted). Working technique had the same
228 effect and significance as recorded for processing cost, being calculated
229 exactly the same way.

230

231 The energy balance was always very favourable. The ration between
232 output and input was never smaller than 59 and peaked at 130 (Figure 2).
233 In other words, processing required about 1% of the energy contained in
234 the firewood - or 1.7% in the worst case. Sorting increased the overall
235 energy efficiency by 40%.

236

237 **Discussion**

238 Despite the significant individual differences, the productivity of all
239 machines on test is comparable, and no machine is dramatically
240 outclassing the others. That was expected, since all machines were fed
241 with the same assortment types, they cut the same stove wood length and

242 they belonged to the same machine size class. Radically different results
243 may have resulted from comparing small-scale with industrial firewood
244 processor, or from feeding different machines with different assortments.
245 Different operator performance may account for part of that variability, as
246 already shown by Lindroos (2008) specifically for firewood processing.
247 Therefore, we may generalize the results of this study to some extent, and
248 state that the productivity of small-scale firewood processors used under
249 southern European conditions commonly varies between 1 and 2 fresh
250 tonnes per hour.

251

252 Such figures are much lower than reported for northern Europe by Kärhå
253 and Jouhiaho (2009), who indicate a productivity range between 4 and 6
254 $\text{m}^3 \text{h}^{-1}$ for machines in the same size class. Part of the difference can be
255 explained by the different measurement units used in the study. Kärhå and
256 Jouhiaho (2009) used cubic meters instead of tons, and net work hours
257 instead of scheduled hours. One cubic meter of spruce or birch is much
258 lighter than a ton, which may reduce the difference between northern and
259 southern figures. What is more, the Nordic productivity figures were
260 inflated by the absence of any delay time in the divider. In contrast, our
261 study included delays up to a maximum duration of 30 minutes, which
262 reduced the final productivity estimate. However, such methodology
263 differences cannot fully account for a factor 3 difference in productivity
264 levels. Therefore, this study seems to confirm the significant effect of
265 regional work conditions on firewood processing performance, as it was
266 hypothesized in the introduction of this paper, and indicated by the same
267 Kärhå and Jouhiaho (2009) in their most interesting study of Nordic
268 firewood processors. Productivity differences are the main reason for the
269 much lower processing cost found in the Nordic study (ca. 10 € t^{-1}), since
270 our labour cost and annual utilization assumptions are very near to those
271 made by the Nordic colleagues.

272

273 Work technique has a powerful effect on productivity, which was also
274 found earlier on by Lindroos (2008), although not to as strong as here (ca.
275 20% instead of 40%). The potential gains obtained through log selection
276 raise the important issue of product strategy, and namely: whether it is
277 best to convert all logs into firewood, or rather divide them between
278 firewood and chip production, through integrated harvesting. In the latter
279 case, logs in the ideal size class range could be used for firewood
280 production, while smaller logs could be diverted to chip production.
281 Processing of more logs in a single batch (i.e. mass handling) may make
282 chipping more efficient than firewood processing when dealing with small
283 logs. Even small chippers manually fed with small logs can exceed the
284 productivity of 1 t h^{-1} reached by the firewood processor under the same
285 conditions (Spinelli and Magagnotti 2010). However, a chipper incurs a
286 higher investment cost and fuel use, which may partly offset the
287 productivity gain over a firewood processor. A desk calculation performed
288 with the Chipcost calculator (Spinelli and Hartsough 2001) allowed
289 estimating the chipping cost of smaller logs as used in this study (diameter
290 10 cm, length 2.1 m) at 38 € t^{-1} , which is about the same cost sustained for
291 turning them into stove wood.

292

293 Nor is fuel efficiency much higher for any of the two options, i.e. firewood
294 or chips. A small scale chipper for rural contractors can use between 1.5
295 and 2.5 l of diesel per ton of chips (Spinelli and Magagnotti 2013), which
296 overlaps quite well with the $1.3\text{-}2.8 \text{ l t}^{-1}$ range found here for the firewood
297 processors.

298

299 We do not deny the potential of product strategy in optimizing biomass
300 operations, but we need to highlight that no option is overwhelmingly
301 superior to the other. Therefore, choosing the best alternative requires
302 exact knowledge of the specific work conditions and some fine-tuning of all
303 operational aspects. At this stage, the only thing one can safely state is

304 that chip production is preferable whenever dealing with the abundant
305 species that cannot be marketed as firewood, such as alder, poplar, willow
306 and most softwoods in Southern Europe.

307

308 Energy efficiency is very high, and in the same order of magnitude
309 recorded for chip production chains (Timmons and Viteri-Mejia 2010,
310 Marchi et al. 2011) after accounting for the different system boundaries
311 considered in these studies. That should ease concerns about the energy
312 performance of traditional firewood production chains.

313

314 Finally, we need to stress that this work focused on small-scale firewood
315 processors rather than on larger industrial units. The latter are widespread
316 all over Europe and are much more productive and expensive to
317 purchase. These are stationary or semi-stationary plants, generally
318 powered by electric motors and designed for advanced automation. Their
319 performance should be investigated with further studies in the near future.

320

321 **Conclusions**

322 Small-scale firewood processor contain some level of automation and are
323 relatively inexpensive, which allows purchase by small-scale companies.
324 However, productivity is relatively low, which results in a high processing
325 cost. Feeding firewood processors with sorted logs is a good way to boost
326 productivity and contain processing cost. Such technique is especially
327 effective with simpler machines, designed for processing one log at a time.
328 Larger units that can handle multiple logs are less sensitive to sorting.
329 Wood species may have a strong effect on productivity, possibly
330 explaining the differences between the northern and the southern
331 productivity figures. Energy efficient is very high, with the processing work
332 requiring a very small proportion of the total energy contained in the
333 firewood.

334

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492 **Table 1** – *Physical characteristics of some tree species used for firewood*

Common name	Latin Name	Density at 15% mc kg m ⁻³	Compression strenght N mm ⁻²	Shear strenght N mm ⁻²	Bending strength N mm ⁻²	Modulus of elasticity N mm ⁻²
Norway spruce	Picea abies Karst.	450	38	6.5	73	15000
Scots pine	Pinus silvestris L.	550	45	7.6	97	13750
Birch	Betula alba L.	650	59	6.0	120	13000
Beech	Fagus sylvatica L.	730	61	8.0	118	14700
Common oak	Quercus robur L.	820	61	9.8	108	12500
Hornbeam	Ostrya carpinifolia Scop.	820	48	8.5	133	12560

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Note: from **G. Giordano 1986**

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Table 2 – Main characteristics of the machines on test

Make		BGU	Gandini	Pezzolato	Pezzolato	Posch
Model		SSA 310	Forest Cut 45	TL750	800	Spaltfix 320
Power source	type	Tractor	Tractor	Tractor	Tractor	Tractor
Tractor power	kW	35	35	33	37	44
Cutter	type	Disc	Chainsaw	Disc	Band	Disc
Cut capacity	cm	30	35	28	40	32
Splitter	type	Hydraulic	Hydraulic	Hydraulic	Hydraulic	Hydraulic
Splitter	travel	Horizontal	Horizontal	Horizontal	Vertical	Horizontal
Splitter	power	11	11	11	12	15
Transfer	type	Gravity	Gravity	Kicker	Manual	Gravity
Weight	kg	900	750	900	700	1450
Operators	n°	1	1	1	2	1
Price	€	12,700	9,200	16,500	8,500	22,000

507 *Note: data obtained from the manufacturers; transfer = method for transferring cut log*
508 *portions to the splitter*
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Table 3 – Costing and energy use: assumptions and total figures

Make Model		BGU SSA 310	Gandini Forest Cut	Pezzoloto TL750	Pezzoloto 800 A	Posch Spaltfix 320
Investment	€	21,700	18,200	24,000	17,500	32,000
Resale (20%)	€	4,340	3,640	4,800	3,500	6,400
Service life	years	10	10	10	10	10
Utilization	h year ⁻¹	500	500	500	500	500
Interest rate	%	4%	4%	4%	4%	4%
Depreciation	€ year ⁻¹	1,736	1,456	1,920	1,400	2,560
Interests	€ year ⁻¹	556	466	614	448	819
Insurance	€ year ⁻¹	2,500	1,922	2,500	2,500	2,500
Diesel	€ year ⁻¹	1929	1929	1819	2040	2426
Lube	€ year ⁻¹	193	193	182	204	243
Maintenance	€ year ⁻¹	1736	1456	1920	1400	2560
Total	€ year ⁻¹	8,650	7,422	8,955	7,992	11,107
Total	€ h ⁻¹	17.3	14.8	17.9	16.0	22.2
Crew	n.	1	1	1	1	1
Labour	€ h ⁻¹	15	15	15	15	15
Overheads (20%)	€ h ⁻¹	6.5	6.0	6.6	6.2	7.4
Machine rate	€ h ⁻¹	38.8	35.8	39.5	37.2	44.7
Energy inputs						
Direct	MJ h ⁻¹	114	114	108	121	144
Indirect	MJ h ⁻¹	50	50	47	53	63
Total	MJ h ⁻¹	164	164	155	174	207

519 *Note: ; Cost in Euro (€) as on November 22, 2013 - 1 € = 135 US\$; investment cost also*
520 *includes the purchase of an old farm tractor, at a price between 7500 and 10000 €*
521 *depending on rated engine power; all machines use standard diesel fuel, and not tax-free*
522 *diesel for agricultural use; h = Scheduled hours, including delays*
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Table 4 – Firewood processing productivity and cost

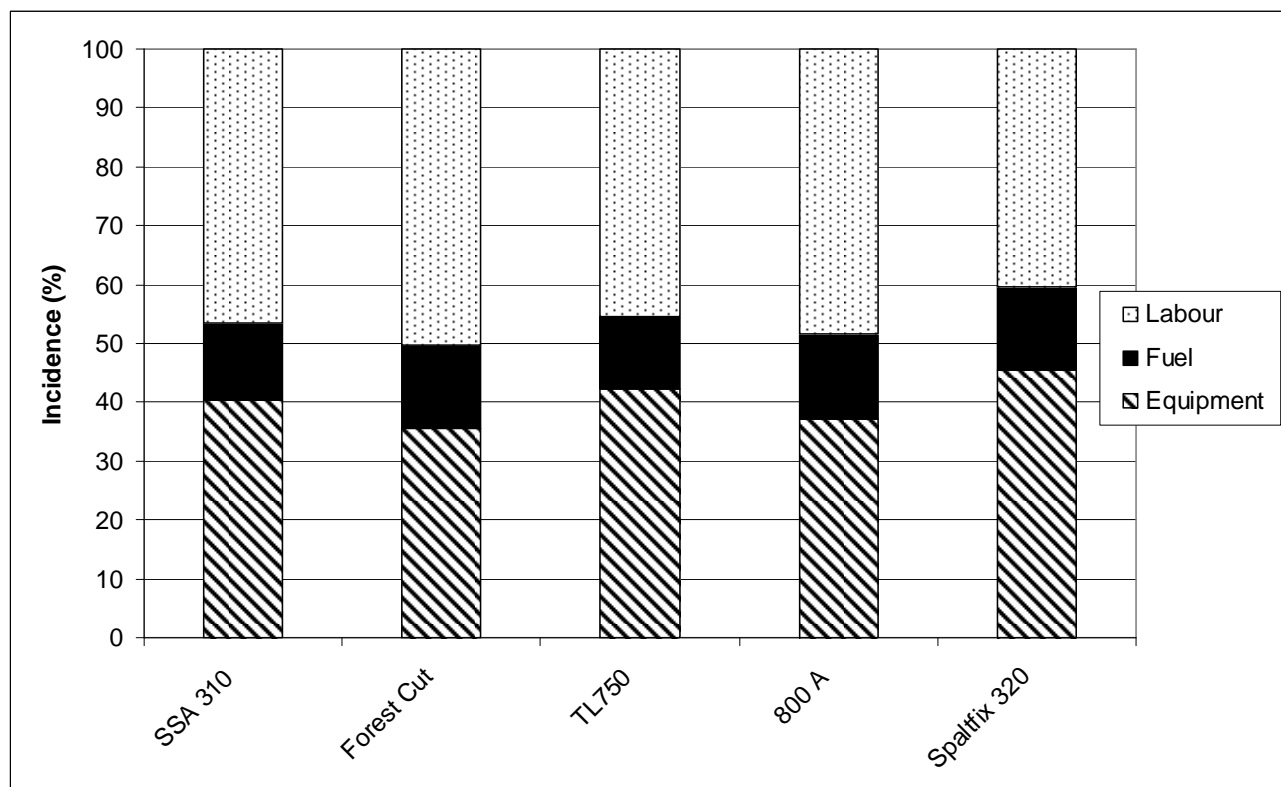
Make	Model	Unsorted	Sorted	Δ %
Productivity (t h ⁻¹)				
BGU	SSA 310	1.05 ^a	1.47 ^a	40
Gandini	Forest Cut 45	1.31 ^{bc}	1.86 ^b	42
Pezzolato	TL750	1.45 ^c	1.80 ^b	24
Pezzolato	A 800	1.42 ^c	2.15 ^c	51
Posch	Spaltfix 320	1.16 ^a	1.58 ^a	36
Processing cost (€ t ⁻¹)				
BGU	SSA 310	37.0 ^a	26.6 ^a	-28
Gandini	Forest Cut 45	28.5 ^b	20.0 ^b	-30
Pezzolato	TL750	27.4 ^b	22.0 ^{bc}	-20
Pezzolato	A 800	39.0 ^c	25.7 ^c	-34
Posch	Spaltfix 320	38.5 ^{ac}	28.3 ^a	-26

534 Note: t = fresh tons, with a 38% moisture content; h = scheduled hour, inclusive of delays;
535 different superscript letter along the same column indicate that the differences between
536 mean values are statistically significant at the 5% level, according to Scheffe's post-hoc
537 test; differences between values on the same row (i.e. unsorted vs. sorted) are
538 statistically significant at the 5% level according to the Wilcoxon Signed Rank test.

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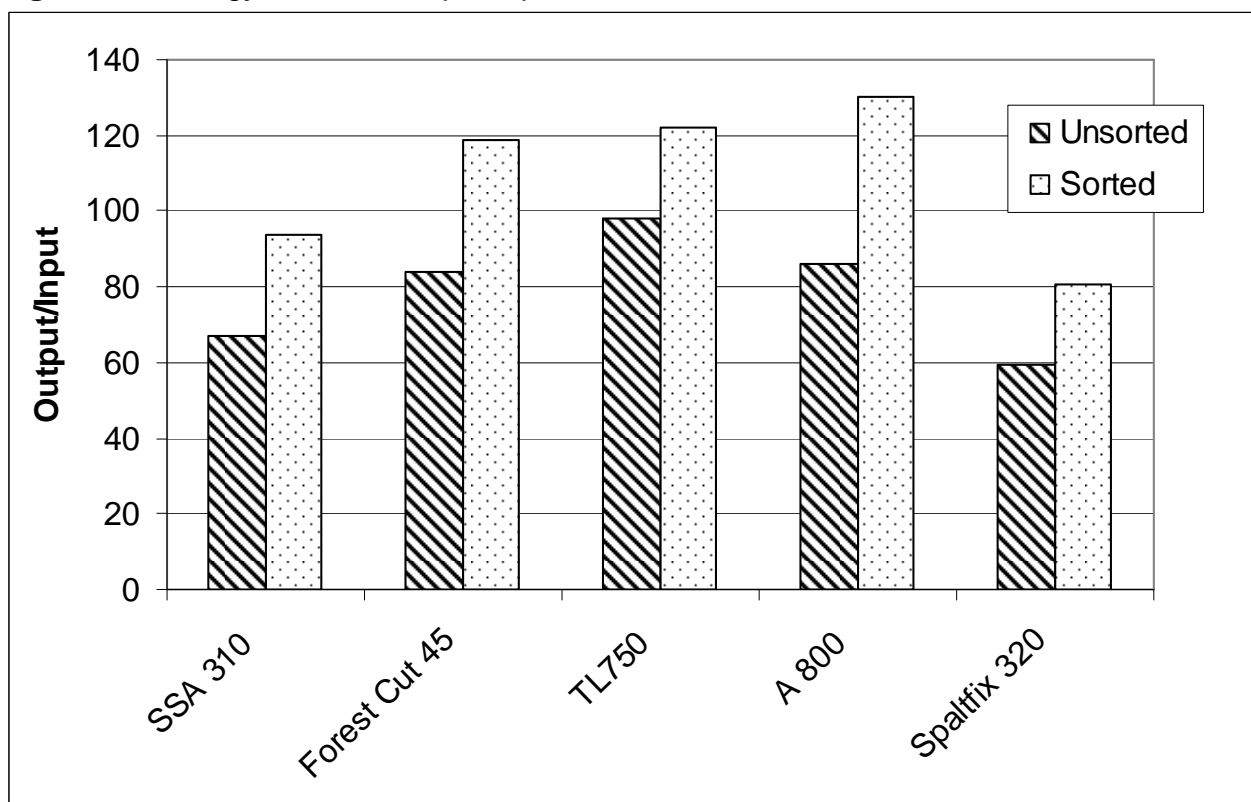
Figure 1– Breakdown of equipment cost by main cost items



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Figure 2 – Energy balance: output/input ratio



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